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COMPARISON OF INDOOR AND OUTDOOR AIR QUALITY AT TWO STAFF QUARTERS IN HONG KONG

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The indoor and outdoor air quality of two staff quarters of Hong Kong Polytechnic University at Tsim Sha Tsui East (TSTE) and Shatin (ST) were investigated. The air sampling was carried out in winter for about two months starting from January to February of 1996. Fifteen flats from each staff quarter were randomly selected for indoor/outdoor air pollutant measurements. The pollutants measured were NO_x, NO, NO_2, SO_2, CO, and O_3. The variations of pollutant concentrations between indoor and outdoor air were investigated on weekday mornings, weekday evenings, weekend mornings, and weekend evenings. All indoor/outdoor pollutant concentrations measured did not exceed the ASHRAE/NAAQS standard. The carbon monoxide concentrations indoors were systemically higher than those outdoors at the TSTE and the ST quarters, both on weekdays and Sunday, which indicates there are CO sources indoors. Except for CO, the indoor levels of other pollutants (NO_x, NO, NO_2, SO_2, and O_3) are lower than those outdoors. There was a significant correlation ($P < 0.05$) between indoor and outdoor concentrations for SO_2 and O_3 at both the TSTE and the ST quarters. Except for O_3, the mean concentrations of all the pollutants in the TSTE quarters, both indoor and outdoor, were higher than that of the ST quarters in all sampling periods. All indoor and outdoor O_3 levels were lower at the TSTE quarters than those at the ST quarters. The O_3 ratios of TSTE/ST were 0.72 outdoor and 0.79 indoor. This can be explained by the NO titration reaction through NO conversion to NO_2. ©1997 Elsevier Science Ltd

INTRODUCTION

Hong Kong is one of the most densely populated territories in the world. As the climate, building structure, ventilation type, and indoor activities of Hong Kong are quite different from other countries, it can provide an interesting study of the relationship between indoor and outdoor air quality.

Robinson and Nelson (1995) estimated that most individuals spend more than two-thirds of the time indoors, either at home, in the office, at school, in restaurants, etc. The measurement of indoor air exposures is critical for the exposure assessment of indoor air pollutants. However, it is difficult to determine the major source of indoor air pollution since indoor air pollutants are emitted from numerous sources (Spengler and Sexton 1983). Several studies have found significant differences between indoor and outdoor pollutant levels. Some studies focused on the suspended matter and sulphur dioxide (Andersen 1972; Kim and Stock 1986; Colome et al. 1990; Dockery and Spengler 1981a, 1981b), nitrogen dioxide (Spengler et al. 1983; Quackenboss et al. 1986; Marbury 1988), heavy metals (Berglund et al. 1992; Akhter and Jowder 1994), volatile organic compounds (Hartwell et al. 1984), and ammonia (Sisovic et al. 1987). It has been shown that an

indoor/outdoor relationship can only be established for those pollutants which are not released indoors, and that the ratio depends on the concentration, infiltration rates, and reactivity of the pollutants (Yocom 1982). The composition of the atmosphere is essentially the same indoors and outdoors, but many studies have indicated that the levels of some pollutants are higher indoors than outdoors (Moschandreas et al. 1987; Madany and Danish 1992). The pollutants that affect the indoor air quality come from a variety of sources: penetration of outdoor pollutants (e.g., carbon monoxide, nitrogen dioxide, sulfur oxides, and street dust), indoor activities (such as smoking, cooking, and incense burning), and the house characteristics (such as air exchange rate, building and furnishing materials).

The objective of this study was to investigate the relationship between indoor and outdoor air pollutants simultaneously at two staff quarters under different periods (weekday mornings, weekday evenings, Sunday mornings, and Sunday evenings). The I/O ratios at these two quarters were also investigated. Six pollutants, including nitrogen dioxide (NO_2), nitric oxide (NO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3), were measured simultaneously indoors and outdoors at each quarter. The concentration variations of pollutants between indoor and outdoor were investigated on weekday mornings, weekday evenings, weekend mornings, and weekend evenings. The I/O relationship between indoor and outdoor pollutants among these two quarters were also compared.

MATERIALS AND METHODS

Field study

Two staff quarters at Tsim Sha Tsui East (TSTE) and Shatin (ST) in Hong Kong were studied. The TSTE staff quarter is a multi-storied residential building situated in the downtown area of Kowloon. It has 14 floors and each floor has 8 flats, totalling 112 flats. The nearby traffic is usually heavy throughout the day as one side of the building faces the Kowloon side entrance of the Cross Harbor Tunnel, while the other side faces a heavily trafficked road. The ST quarter is also a multi-storied complex located in the suburban area of Shatin. It has 5 to 17 floors. There is only light traffic load in the nearby roads. The sources at the TSTE quarter were mainly from the vehicular emissions while at the ST quarter, in addition to vehicular emissions, another possible source was the near-by Industrial Area. For each quarter, 15 flats were randomly selected to investigate the indoor/outdoor air quality on weekdays and weekends during the morning and evening periods.

Sampling and analysis

Indoor and outdoor air samples were taken from 15 flats at each quarter. Sampling was conducted from January to March of 1996 at the TSTE and the ST staff quarters. Air samples were taken from each flat at four different periods including weekday morning, weekday evening, Sunday morning, and Sunday evening. During each period, an indoor air sample was collected at the living room and an outdoor sample was collected simultaneously at the balcony. During sampling, various indoor parameters were recorded. These included the floor of the flat, the number of cigarettes smoked, the application of air cleaner, heater, and the number of carpets, etc.

The sampling location of the air, both indoor and outdoor, was at the respiratory level (i.e., 1.5 m above the ground) and also free from any direct obstructions. Both outdoor and indoor air samples were collected simultaneously by the same methods. The air was collected in a 25 L Tedlar sampling bag by a small portable air pump (Airchek sampler, Model 224-43XR) with adjusted flow rate at 1 L/min for 20 min. All air samples were immediately transported to the central laboratory for analysis. The NO_x (including NO and NO_2) was measured with Thermo Electron (model 42) chemiluminescence NO_x Analyzer (Range: 0 - 20 μL/L, Precision: 0.5 nL/L). The SO_2 was measured with Thermo Electron model 43B, Pulsed Fluorescence SO_2 Analyzer (Range: 0 - 100 μL/L, Precision: 1 nL/L). The CO was measured with Thermo Electron model 48, Gas Filter Correlation CO Ambient Analyzer (Range: 0 - 1000 μL/L, Precision: 0.1 μL/L). The O_3 was measured with Thermo Electron model 49, Ultraviolet Photometric Ozone Analyzer (Range: 0 - 1 μL/L, Precision: 2 nL/L). The change of the pollutant concentration with time lag inside a sample bag was investigated. The effect of time lag on the concentration measurement of pollutants is negligible (error less than 1% for SO_2, NO, NO_2, and CO and less than 5% for O_3) within 3 h after the samples were collected and transported to the laboratory.

In order to investigate the relationship between indoor and outdoor pollutant levels, indoor measurements were first divided by matched outdoor mea-

surements and then arithmetic mean, standard deviation, and I/O ratios were calculated at each quarter. A statistical analysis of the correlation between indoor and outdoor concentrations of each pollutant was then performed.

RESULTS AND DISCUSSION

Comparison of indoor/outdoor air quality at two staff quarters under different periods

Figures 1 and 2 show the indoor and outdoor average concentrations of NO_x, NO, NO_2, SO_2, CO, and O_3, at the TSTE quarters and the ST quarters measured in the weekday morning, weekday evening, Sunday morning, and Sunday evening. Except for some cases where NO_2 exceeded the limit (0.05 μL/L, annual average), both NO_2 concentrations of air pollutants at the two quarters are much lower than the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard for indoor air pollutants and the USA National Ambient Air Quality Standard (NAAQS) for outdoor air pollutants. The considerably high NO_2 indoor level was probably contributed by the outdoor fuel burning from exhausted gases and indoor gas emissions from the cooking appliance.

Statistical analysis on air quality at different periods was conducted. For both indoors and outdoors, air quality did not show significant differences between the morning period and the evening period at the two quarters, as all the P-values were greater than 0.05. This implied that the air quality is similar in the morning and in the evening. However, significant differences (P-value < 0.05) between weekday evening and Sunday evening were found for SO_2 at the TSTE quarters. The mean indoor SO_2 concentration for weekday evening and Sunday evening is 5 nL/L and 4 nL/L while the outdoors is 6 nL/L and 5 nL/L, respectively. The possible reason is that the traffic flow is much lower on Sunday evenings compared with that on weekday evenings. On the contrary, the outdoor pollutant levels (NO_x) on Sunday mornings were higher than that on weekday mornings at the ST quarters. The mean NO_x levels were 37.7 and 28.1 nL/L on Sunday mornings and weekday mornings, respectively.

I/O correlation between indoor and outdoor air quality

The results of measurements are presented in Table 1 for the TSTE quarters and in Table 2 for the ST quarters as the number of measurements, arithmetic mean, and standard deviation of various pollutant concentrations measured outdoors (O) and indoors (I) as well as the I/O ratios and the P value between indoor and outdoor concentrations. At both of the two quarters, the mean I/O ratios of CO are all greater than 1, with 1.29 at TSTE and 1.27 at the ST quarter. The I/O ratios of CO varied from 1.14 to 1.55 at the TSTE quarters and 1.14 to 1.44 at the ST quarters under different periods (weekday morning, weekday evening, Sunday morning, and Sunday evening). The carbon monoxide concentrations indoors were systemically higher than those outdoors at the TSTE and the ST quarters, both on weekdays and Sunday, which indicates there are CO sources indoors. For both quarters, the peak I/O ratios were always detected at the flats where the kitchen ventilation system is not on while the residents cooked dinners. Except for CO, the indoor levels of other pollutants (NO_x, NO, NO_2, SO_2, and O_3) are lower than those outdoors. At both of the two quarters, the mean I/O ratios of NO_x, NO, NO_2, SO_2, and O_3 are all less than 1. The mean I/O ratios for different pollutants (NO_x, NO, NO_2, SO_2, and O_3) ranged from 0.72 - 0.98 at the TSTE quarters and 0.89 - 0.98 at the ST quarters. Under the sampling periods, the indoor concentrations of NO_x (NO and NO_2), SO_2, and O_3 were lower than outdoor concentrations where indoor sources are absent or negligible.

Among all the pollutants measured, there was a significant correlation ($P < 0.05$) between indoor and outdoor concentrations for SO_2 and O_3 at both the TSTE and ST quarters. For other pollutants (NO_x, NO, NO_2, and CO), there was no significant correlation ($P > 0.05$) between indoor and outdoor concentrations. The indoor SO_2 and O_3 were mainly from outdoor sources, while the indoor NO, NO_2, and CO might either come from outdoor or from indoor sources such as tobacco smoking, gas stoves, burning incense, candles or mosquito coils, and operating a heater. The above result is similar to the study by Kim and Stock (1986) which suggests that the indoor air pollutants appear to be affected by infiltration of outdoor air as well as by indoor generation.

The comparison of the average concentrations outdoors and indoors at TSTE and ST is shown in Table 3. Most of the pollutants indoors and outdoors at the TSTE quarters were significantly higher than those collected at the ST quarters in all sampling periods. Except for O_3, the TSTE/ST ratios of indoors and outdoors is greater than 1 for all pollutants (NO_x, NO, NO_2, SO_2, and CO). This shows the TSTE quarters has

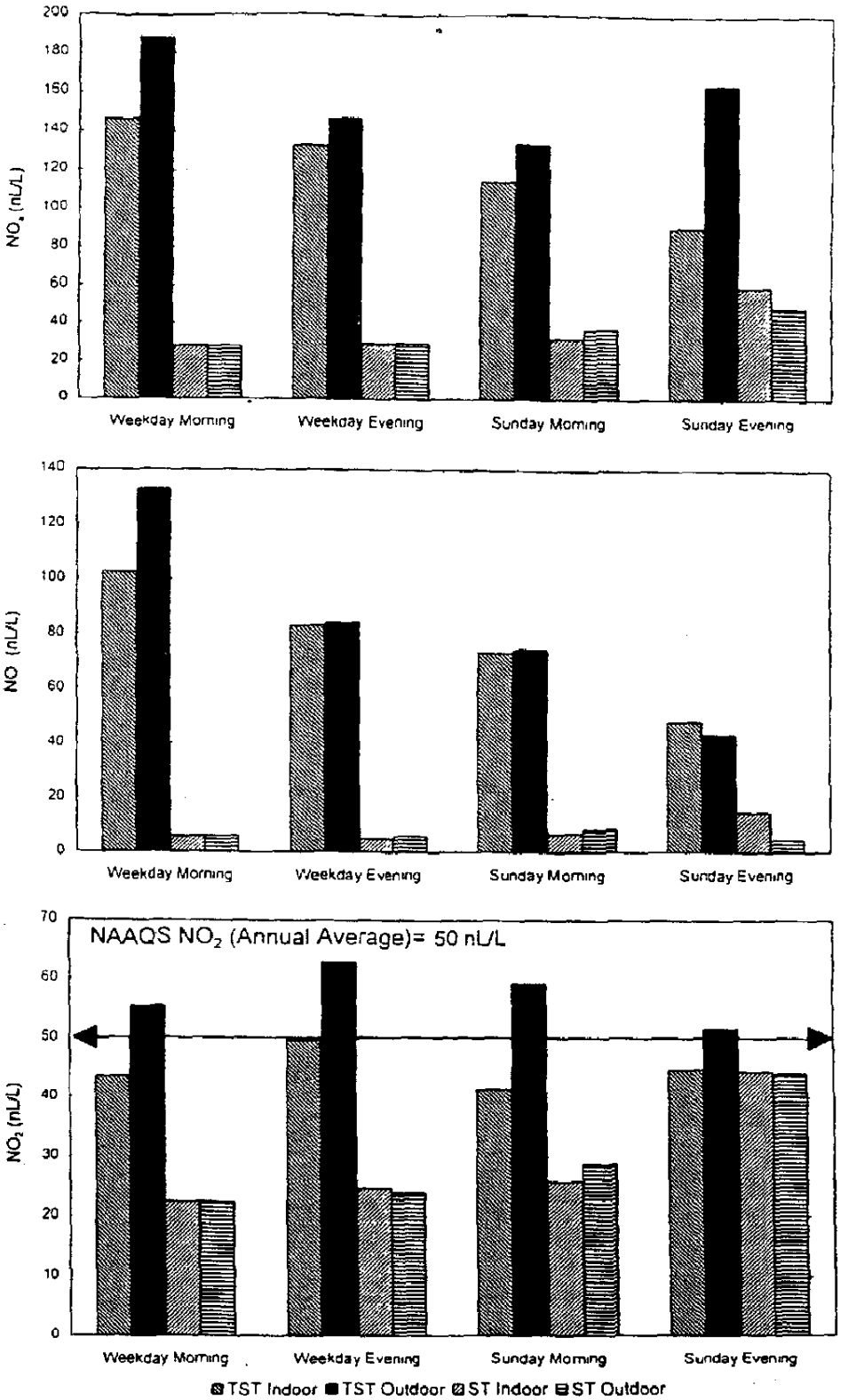

Fig. 1. Indoor/outdoor pollutant concentration at the TSTE and ST quarters during different sampling periods: (a) NO_x, (b) NO, and (c) NO_2.

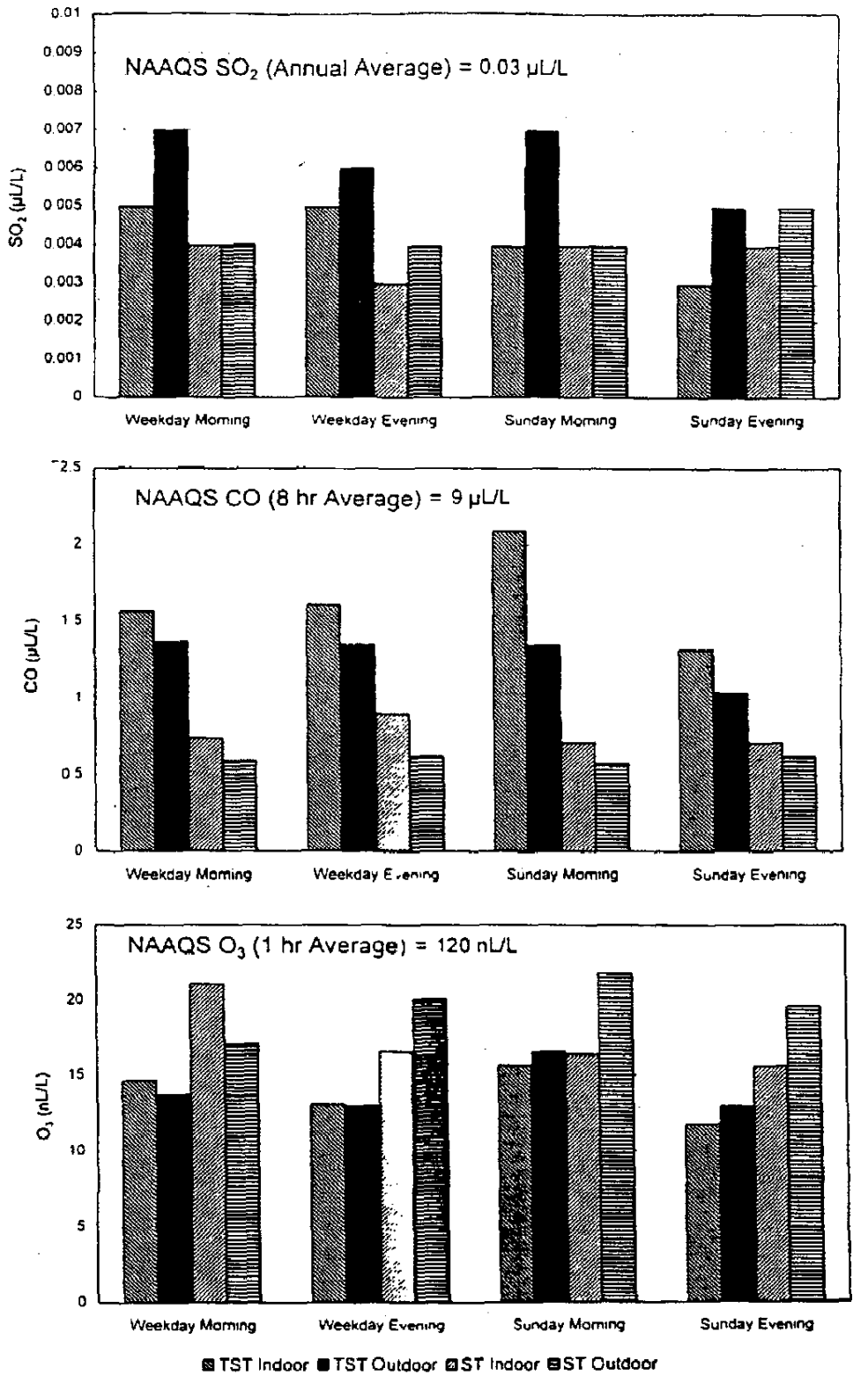

Fig. 2. Indoor/outdoor pollutant concentration at the TSTE and ST quarters during different sampling periods: (a) SO_2, (b) CO, and (c) O_3.

Table 1. Comparison of indoor/outdoor pollutant concentrations at the TSTE quarters.

	No. of data	O_{mean}	$O_{s.d}$	I_{mean}	$I_{s.d}$	I/O_{mean}	I/O_{range}	P value
NO_x	120	141	75.6	121	67.2	0.86	0.78 - 0.95	0.257
NO	120	83.7	68.1	76.7	60.8	0.92	0.77 - 1.10	0.246
NO_2	120	57.6	13.0	44.8	15.1	0.78	0.70 - 0.87	0.253
SO_2	120	6.0	2.5	4.3	1.4	0.72	0.54 - 0.85	0.006*
CO	120	1.28	0.44	1.65	1.0	1.29	1.14 - 1.55	0.119
O_3	120	14.1	4.4	13.8	3.65	0.98	0.90 - 1.07	0.005*

Unit: All concentrations in nL/L except CO in μL/L.
* P-value < 0.05, i.e., statistically significant difference between the concentration of indoor pollutants and outdoor pollutants.

Table 2. Comparison of indoor/outdoor pollutant concentrations at the ST quarters.

	No. of data	O_{mean}	$O_{s.d}$	I_{mean}	$I_{s.d}$	I/O_{mean}	I/O_{range}	P value
NO_x	120	36.2	16.4	35.4	23.0	0.98	0.86 - 1.21	0.159
NO	120	6.4	5.7	6.1	10.4	0.95	0.77 - 3.14	0.11
NO_2	120	29.8	13.0	29.3	16.1	0.97	0.89 - 1.03	0.191
SO_2	120	4.3	1.3	3.9	1.0	0.91	0.86 - 0.97	0.034*
CO	120	0.6	0.1	0.76	0.4	1.27	1.14 - 1.44	0.836
O_3	120	19.7	6.0	17.5	6.7	0.89	0.75 - 1.23	0.004*

Unit: All concentrations in nL/L except CO in μL/L.
* P-value < 0.05, i.e., statistically significant difference between the concentration of indoor pollutants and outdoor pollutants.

Table 3. Comparison of indoor and outdoor pollutant concentration ratio between the TSTE quarters and the ST quarters

	Outdoor			Indoor		
	TSTE	ST	TSTE/ST	TSTE	ST	TSTE/ST
NO_x	141	36.2	3.9	121.1	35.4	3.42
NO	83.7	6.4	13.07	76.7	6.1	12.57
NO_2	57.6	29.8	1.92	44.8	29.3	1.53
SO_2	6	4.3	1.45	4.3	3.9	1.10
CO	1.28	0.6	2.13	1.65	0.76	2.15
O_3	14.1	19.7	0.72	13.8	17.5	0.79

Unit: All concentrations in nL/L except CO in μL/L.

worse air quality both indoors and outdoors than the ST quarters. All the indoor and outdoor O_3 levels were found to be lower at the TSTE quarters than at the ST quarters. The O_3 ratios of TSTE/ST were 0.72 outdoor and 0.79 indoor. This can be explained by the NO titration reaction through NO conversion to NO_2 ($NO + O_3 = NO_2$). The NO ratios of TSTE/ST were 13.07 outdoor and 12.57 indoor, so the NO titration reaction has significant effects and results in a lower ozone level both indoors and outdoors at the TSTE quarters.

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